consultations with the district forester and the several supervisors in this district. There are many factors deserving of careful study and investigation which are conducive to starting forest fires and also to aggravating a fire already started.

The condition of the humus on the forest floor is a matter of vital import. No serious fire may be expected until after it has become quite dry, and probably the rate of evaporation at the surface is proportional to the fire hazard. Assuming this, we must next determine what meteorological factors can be safely taken as an index for the rapid drying of the forest floor. These, I believe, can safely be reduced to two, a drying wind or very warm weather. A north or northeast wind, although light, causes a decided drop in the humidity in California, and consequently a rapid drying of the forest floor; also high temperatures in this State are invariably accompanied by low humidity, causing the same rapid drying condition. If the temperatures are only moderately high, they will have to continue for several days before the humus is sufficiently dry to become dangerous. Any combination of the above-named conditions will be conducive to hastening the drying process and raising the fire hazard.

Once a fire has started, dry winds and warm weather greatly tend to increase its energy, the increase being proportional to the velocity of the wind and intensity of the hot spell. Cloudy weather, particularlly if accompanied by winds coming off the ocean and carrying a high percentage of humidity, are factors that in a marked degree mitigate against the rapid spread of a fire. A shower of 0.25 inch will, in nearly every case, bring a fire under perfect control, and in many cases even 0.10 inch will so reduce a fire's energy that it can be easily handled.

From the forester's standpoint there are other serious factors to be considered, among which are the character of the undergrowth and its density, the topography of the country and the availability of men for emergency service and their transportation to the fire zone. His fire hazard also increases as the number of people frequenting the forests increases, and from many other causes.

In addition to the information shown on the weather map and from special observations, whenever a ranger on lookout duty stationed on some high peak, observes the wind to be blowing from the north or northeast at a rate of 10 miles per hour for one hour, he telephones the supervisor to that effect, and if two such reports are received, the supervisor immediately telephones the district forester's office in this city, and he in turn notifies the district forecaster. If it is decided to issue a fire warning, the district forester is advised of the necessity for such warning, given the forecast and the sections to which it applies. The forester then distributes the warning to his supervisors, who in turn telephone it to all rangers and make preparations for any emergency that may arise.—*G. H. Willson.*

Chicago, Ill., District.[3]—In 1914 six warnings were sent to northern Minnesota and one to western Montana.

In 1915 five warnings were sent to northern Minnesota, all during the month of June. At the request of the section director at Minneapolis messages, even for moderate breezes, were sent to the foresters during the critical season in June.

"Fire-wind" warnings have not been issued to any great extent during the past two seasons to the States in this district listed for them, viz, northern Minnesota, western South Dakota, Montana, and Wyoming. This is partly due to the absence of deep lows or strong winds during the critical season, and to more than the usual rainfall, especially in 1915. The messages have been sent during the periods specified by the section directors, being discontinued upon their telegraphic request.

I have no information upon the subject of benefits from the warnings issued.—*H. J. Cox.*

[3] Extracts from report by the district forecaster, Chicago, Ill., of Nov. 23, 1915.

DROUGHTS AND HOT WEATHER.[4]

By E. A. BEALS, District Forecaster.

[Weather Bureau, Portland, Oreg., December, 1915.]

When the forest litter is wet it is hard to start a forest fire; when dry it is easy, therefore a prerequisite of a forest fire is a drought. Drought has never been defined in definite terms, but the common meaning is long-continued dry weather, especially so long continued as to cause vegetation to wither. Vegetation withers when deprived of moisture, and, while lack of rain is essential, another important factor is evaporation. When evaporation is rapid, the injurious effects of dry weather are intensified, and when it is slow they are mitigated. The amount of evaporation depends on a number of things, the most important of which from a meteorological standpoint are humidity, temperature, wind, and barometric pressure (3).

Evaporation is accelerated when the humidity and pressure are low and the temperature and wind are high. As there are no means of correctly measuring evaporation from a forest cover, it is necessary to consider the factors causing rapid evaporation in order to determine the extent of the fire danger to which a forest is exposed. Of these factors, which consist of low humidity, low pressure, high temperature, and high wind, the Weather Bureau furnishes the public with predictions of the two most essential, viz, high temperatures and high winds.

Of the remaining factors, that of low pressure exerts a minor influence on evaporation, and while not specifically included in the forecasts, the areas of low pressure are usually described in the notes accompanying weather maps, and the maps show their location as well. When fire-weather forecasts are made, the locations and movements of both the low and high pressure areas are included in each forecast.

No attempt has been made to predict humidity, but it is understood by the public on the Pacific slope that when hot weather prevails the humidity will be low, and a prediction of hot weather during a drought practically covers both elements.

HIGH WINDS.

High winds in combination with drought cause far greater losses through their influence in fanning the flames than in their effect on evaporation, therefore they should be treated separately, which leaves high temperatures during droughty periods as one of the principal elements requiring attention when making predictions of weather favorable to an increase of forest fires.

Should the wind increase to a moderate breeze, or stronger, as defined by the Beaufort scale, it is almost impossible to extinguish a forest fire. Moderately high winds from any direction are dreaded by forest-fire fighters, but in the Pacific States those from an easterly direction are dreaded more than those from any other direction, as they are invariably parching winds that sap the vitality of the trees, and rapidly dry out the leaf litter and duff.

[4] Extracts from paper, "Forecasts of weather favorable to the increase of forest fires," read before the Pan-American Scientific Congress at Washington, D. C., Dec. 30, 1915.

There are three classes of winds on the Pacific slope that blow at times at as great or at a greater velocity than a moderate breeze. They are cyclonic winds, mountain and valley breezes, and land and sea breezes. Both the mountain and valley and the land and sea breezes are greatly modified by those due to cyclonic action.

The cyclonic winds can be forecast without much difficulty, but the variations that take place, both in their direction and velocity, on account of the influence of the other breezes, as well as the deflections that take place because of topography, usually cause unsatisfactory verifications. It is the cyclonic winds that are now being predicted when it is thought they will be sufficiently strong to be the dominating factor, and by sufficiently strong is meant winds having a velocity of 15 or more miles an hour.

FIRES CAUSED BY LIGHTNING.

The only uncontrollable cause of forest fires is lightning, which, as everyone knows, is the distinctive feature of thunderstorms. One would think that the rain attending the thunderstorm would put out any fire that might be started by lightning, but often there is so little rain that this is not the case.

Forest Service statistics show that for the period from 1908 to 1914, inclusive, there were 3,548 fires known to have been started by lightning in the national forests in Oregon, Washington, Alaska, Montana, Idaho, Wyoming, Colorado, and the western portion of the Dakotas, which makes an average of slightly over 500 a year.

Very little has been done by the Weather Bureau toward predicting the thunderstorms that are accompanied by the lightning which sets fire to forests. Rapid vertical convection of humid air is essential to the generation of thunderstorms, and Prof. W. J. Humphreys (4) gives three ways in which this circulation can be established, as follows:

(*a*) Strong surface heating, especially in regions of light winds; a frequent occurrence.

(*b*) The overrunning of one layer of air by another at a temperature sufficiently lower to induce convection; well-nigh the sole cause of ocean thunderstorms and also of frequent occurrence on land.

(*c*) The underrunning and consequent uplift of a saturated layer of air by a denser layer; a frequent occurrence to a greater or lesser extent, and presumably therefore at least one of sufficient magnitude to produce a thunderstorm.

The first method is the most favorable for thunderstorms in mountainous regions where the forests are situated and weather forecasting is not far enough advanced to make satisfactory predictions of this class of storms. Thunderstorms generated by the second or third method can generally be predicted, but as they seldom occur during the season for fires in the forested sections west of the Rocky Mountains there is not often an occasion for predicting them.

To arrive at a better understanding of the kind of weather that should be predicted for the forest people, my method was to ascertain the dates when a number of fires had occurred in the past and then prepare charts showing the weather conditions prevailing from 6 to 24 or more hours prior to the fires. Quite a number of these types are kept at the Portland weather office, where they are available for reference purposes at a moment's notice. Four of these charts were prepared on a small scale for this occasion, as well as eight others, showing conditions upon which actual forecasts were based during the last two fire seasons.

From the charts that have been prepared to show weather conditions just preceding some of the large fires in the past, it is learned that in every case the fires did not become dangerous until after a small increase in the velocity of the wind had taken place. This small increase in the velocity of the wind can usually be predicted sufficiently far enough in advance to make the forecasts of great value to the forest fire fighters.

Winds causing the rapid spreading of forest fires are usually those associated with cyclones, except in the Pacific States where they are as a rule those associated with anticyclones. The latter type is considered the most dangerous, as the winds attending anticyclones on the Pacific slope during the summer months are always very dry and warm.

ACTUAL FIRE-WEATHER FORECASTS.

Although the forecasting of fire weather began in the North Pacific States during the summer of 1913, it was not until the summer of 1914 that sufficient study had been given the subject to warrant forecasts of this class being systematically made.

Reports were received from the field showing that these forecasts were for the most part verified, and that they were of benefit to the fire fighters, but no one knows better than myself that there is room for improvement, and more study will have to be given the subject before any great advancement can be made in predicting weather favorable for the spread of forest fires.

PRESENT CONDITION OF THE FIRE-WEATHER FORECASTING SERVICE IN THE NORTH PACIFIC STATES.

The present condition of the fire-weather forecasting service in the North Pacific States can be summed up as follows:

The season for forest fires includes July, August, and the first half of September, though fires sometimes occur in May and June.

When dry weather has prevailed for a sufficient period to make forest fires possible, which question is determined empirically, forecasts are issued when the conditions are favorable for fresh breezes or for a spell of hot weather.

Special pains are taken to forecast fresh or brisk north, northeast, or east winds, as they are always attended by low humidity and are more dangerous on that account than those from any other direction.

Each forecast is worded to show (*a*) position of the dominating high and low pressure areas, (*b*) apparent direction and speed of their movements, (*c*) character of winds and temperature expected for as long a period ahead as possible, and (*d*) such cautionary advice as is thought necessary.

Fire-weather forecasts are telegraphed at Government expense to district foresters, and to the chief wardens of forest protective associations, and by them distributed to their men as they see fit.

What is needed to improve the service.

In advancing opinions as to what should be done to improve the service, the conditions in the North Pacific States alone are considered. Other districts very likely will require treatment modified according to their special needs.

Knowledge regarding the weather that prevails in the forests is meager, as the reporting stations are all in the valleys, often many miles away, and the few cooperative stations in the forests are only equipped with rain gauges and thermometers. The first essential, therefore, is to divide the territory into convenient units, when a careful meteorological survey of each should be made.

This survey should show during the forest-fire season the prevailing winds, their hourly velocity, the frequency of gales, daily precipitation, periods of drought measured on a uniform scale, the daily a. m. and p. m. humidity, the maximum and minimum temperatures, and if possible the daily rate of evaporation. In addition, observations of thunderstorms and of other natural phenomena should be made. These data, when obtained, should be graphically represented on charts and correlated with those forest conditions that tend to increase or diminish the fire hazard, such as inflammability, risk, controllability, liability, and safety. When this has been done it will be possible to determine when an emergency exists which will make necessary the dissemination of fire-weather forecasts, should the weather conditions from that time on justify their being made. Also there will be data available which will enable the forecaster to adjust his forecasts to meet conditions in more restricted localities than at present.

As an illustration of what could be done along these lines, an extract from an unpublished report (6) by Forest Supervisor W. L. Merritt and Mr. W. J. Sproat, from data obtained without instruments in the Deschutes and Deschutes division of the Paulina Forests, follows.

1. The normal wind movement seems to be from an eastern direction in the morning and early forenoon, and from a western one in the afternoon. Severe winds almost invariably blow from some westerly direction, and not from the east, as has sometimes been stated. General eastern winds apparently are not dangerous in this locality.

2. Generally the wind dies down at night and does not become severe until about 10 a. m. the next day. Every effort should be made, therefore, to control fires before that hour of the morning.

3. It is thought the winds are not extremely dangerous until after the velocity exceeds about 15 miles an hour. When the rate is this amount it is extremely difficult to control fires that may be burning.

4. A study of the chart of general conditions in Oregon and a general knowledge of the topography and conditions throughout the eastern portion of the State seem to indicate that severe windy periods come after the high desert region has become excessively heated during the period of high temperatures, causing low-pressure areas and resulting in a strong wind movement toward the east.

5. Although no smoke records were kept last summer, it was our general observation that smoky conditions were coincident with severe windy periods, no doubt due to the fact that eastward air movements brought smoke from the west slope of the Cascade Divide.

6. It is probable there is some relation between lightning storms and the causes which precede severe windy periods. Since no records were kept of lightning storms last summer, however, this point can not be stated with certainty. Lightning records will be kept during the coming season.

In another part of the report by Messrs. Merritt and Sproat, it is stated that "Although the wind records for that day did not show that the conditions were bad, the wind really blew very hard at the fire itself."

It is well known that forest fires cause strong convectional currents and that inflowing surface winds of greater or less velocity result therefrom (7). This interesting phenomenon should be thoroughly investigated, as next to nothing is now known regarding the extent of area surrounding fires that is thus affected.

Dry periods are not classified and published by the Weather Bureau, and, furthermore, there are at present only a few places in the forests where a record of the weather is kept; therefore very little is known regarding actual periods of drought in the timbered regions west of the Rocky Mountains. That rainfall on the Pacific slope increases with altitude is well known, also that the forests in that section are nearly all located on the sides of the mountains, consequently the rainfall in the valleys some distance away is a poor guide upon which to base an estimate of the amount that falls in the more elevated regions where the forests are situated.

The establishment of weather stations on mountain slopes where there are forests is difficult of accomplishment, unless the observers are paid a salary sufficient to make the observation work their chief occupation, and to do this would so increase the cost as to make the service prohibitive. There are so few settlers in forested regions that it is seldom possible to obtain the services of a good observer who is willing to undertake the work of keeping a weather record without pay. The forest rangers are not available, as the nature of their work keeps them away from their homes a good part of the time and particularly during the season for forest fires, when it is most important that no break occur in the weather records.

It is possible, however, from time to time to obtain good observers in the forests who are willing to serve without pay, and when such an opportunity occurs it is believed a weather station should at once be established, as the cost of the instruments and blanks is small when compared with the value of the data obtained.

Temperature data obtained in the cities will represent fairly well the conditions prevailing in the forests, at least to the extent that when the weather is warm in the cities it will be relatively warm in the forests, and vice versa. It will not be necessary, therefore, to establish as many temperature-recording as rainfall stations.

The percentage of fires started by lightning is large, but the hazard from this cause is not so great as indicated by the statistics, as lightning seldom sets fire to a green tree (8). After the snags and stubs are removed the danger of forest fires from lightning will be greatly reduced. It will, however, take many years to remove the dead trees from forested areas, and careful records of thunderstorms should be made for some time to come.

Thunderstorms in mountains are most frequent during the afternoon, and they are especially liable to occur near the end of two or three days of hot weather (4). After sufficient data have been secured it may be possible to predict the days when and the places where they are most likely to occur.

CONCLUSIONS.

According to United States Forest Service statistics (9), forest fires in the United States have caused an annual loss of about 70 human beings, the destruction of trees worth at the very least $25,000,000, and the loss of stock, crops, buildings, and other improvements to the amount of many millions more. Forest fires under the present system of control seldom cause much loss, except when the wind increases to 15 miles or more an hour, when it is impossible to extinguish them.

Advanced information of when to expect winds of this character will enable those in charge of putting out forest fires to increase their fire crews, stop burning permits, and to take other precautionary measures which might be the means of preventing destructive fires; therefore it is believed that the effect of weather on forest fires is deserving of careful study by meteorologists in all parts of the world, and especially by those in the United States, that a way may be devised to improve the forecasts of

wind, as well as the forecasts of other elements that cause an increase in the number of forest fires.

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HOW THE WEATHER BUREAU CAN HELP.[5]

By E. A. BEALS, District Forecaster.

[Weather Bureau, Portland, Oreg., October, 1915.]

To estimate the probable intensity of a forest-fire hazard we need to begin our analysis of the weather as far back as the preceding October or November, especially as regards snowfall in the mountains. The destructive fires in 1910 were primarily due to a deficiency in snowfall during the winter of 1909–10, which was followed by a warm March that caused most of the snow to disappear by the 1st of April, or two months earlier than usual. The rains during the warm months that followed were light. The humus in the forest became dry, and fires were prevalent early in the year. They had obtained good headway in many localities long before the season for them had arrived.

During the winter of 1914–15 the snowfall was even less than in 1909–10, in fact, every report received last spring showed less snow on the ground than in the last 20 or more years. The beginning of this season was, therefore, more inauspicious than in 1910. They say the Lord favors the shorn lamb, and He must have had the lumber interests in mind when He gave the parched earth such bountiful showers last May and July (1915). It was the excess of rain in those two months that saved us from what might have been as bad a season for forest fires as any we have had in recent years. We were also favored by not having any very high winds to contend with during the height of the fire season, which did not really begin until August, and the worst part was over about September 10.

June, 1915, was drier than was June, 1914, in Oregon, Washington, and Idaho, and it was a little warmer in the first two States and a trifle cooler in Idaho. July, ordinarily dry, was a wet month in 1915, with 280 per cent of the normal rainfall in Oregon, 130 per cent in Washington, and 145 per cent in Idaho. July was also cooler than last year in all three States. If the following August had only followed July's example, we should have had no serious trouble with fires this year; but that month was not only about as dry as it was a year ago, but, in addition, it was considerably warmer. It was the fires started during this month that caused the greatest apprehension, and they taxed the fire-fighting strength under the control of some of your wardens and supervisors to their utmost.

Our forecasting in 1915 followed the same lines as in 1914, and while not up to the mark we have set for attainment, I am more convinced than ever the service is of help to the fire fighters, and it promises to be of value in lines not thought of before this season.

Three "sets" of fire-weather forecasts were issued—one in July, one in August, and one in September. The forecasts issued in September were verified in only a few places, while the others were fairly reliable, especially the one in August, which covered the worst period for fires in western Washington and northwestern Oregon (the territory to which it was limited).

Another way whereby the Weather Bureau can help those having charge of the work of putting out forest fires will be in the advice we are able to give regarding the daily weather conditions. If the fires are under such control that the conditions would be shaky if the winds increased, the question comes up whether to lay the men off or hold them for the contingency of high winds arising in the near future. Also we may have a local rain which would lead the man on the ground to believe all immediate danger has passed, and he would let his men go, when as a matter of fact the rain was insufficient and only temporary relief was obtained. Before he could get his men back losses might occur that would have been prevented if he had held them. In these small ways I feel sure we can be of help to those in doubt as to the procedure that should be taken.

Next year we hope to send "hot weather" forecasts to every post office in the neighborhood of forests, at least in the three Northwestern States. They will be printed on post cards and, besides the forecasts, will contain words of caution to campers and others who visit the forests about starting and putting out camp fires, etc. We hope that this card, issued in conjunction with the forecasts, will be posted in the country post offices and that it will help to impress the public with the importance of taking more care in these matters. Many fires obtain their start through sheer carelessness, and the public should have their attention called to preventative measures from as many angles as possible. The weather forecast will first attract the eye, and when the announcement "hot weather" is read the corollary of the increasing fire hazard will be impressed upon the readers by the accompanying notes on the caution that should be exercised by campers to prevent the spreading of their fires. If, through this card, only one "class C" [6] fire is prevented it will much more than pay for the cost of the service.

Perhaps the most important step taken this year which will operate toward the efficiency of the fire-weather forecasts is the inauguration of nine lookout stations in the national forests of Oregon and Washington, which have been equipped with instruments for measuring and recording the velocity of the wind, the humidity, temperature, and rainfall. We hope the records kept at the high altitude of these stations will give information that will enable us to increase the time limit ahead of the occurrence of changes in the weather. This is important, for every hour in advance of a change to worse weather permits more preparation to avert the threatened damage.

[5] Extracts from paper "Fire-weather forecasts: where and how they prove effective," read before the Forest Industry Conference at San Francisco, Cal., Oct. 19, 1915.

[6] The United States Forest Service classifies forest fires, in its annual statistical statements, according to the area burned and designates the classes as follows:
Fires of class A are those covering less than one-fourth acre.
Fires of class B are those covering not more than 10 acres.
Fires of class C are those covering more than 10 acres.
Prior to 1912 fires of class B covered areas under 5 acres, and class C fires covered areas of 5 acres and over.—C. A., jr.